PRISM/PRIME
the Advanced Muon Beam
and
the Experiment Searching for
μ-e Conversion with 10^{-18} Sensitivity

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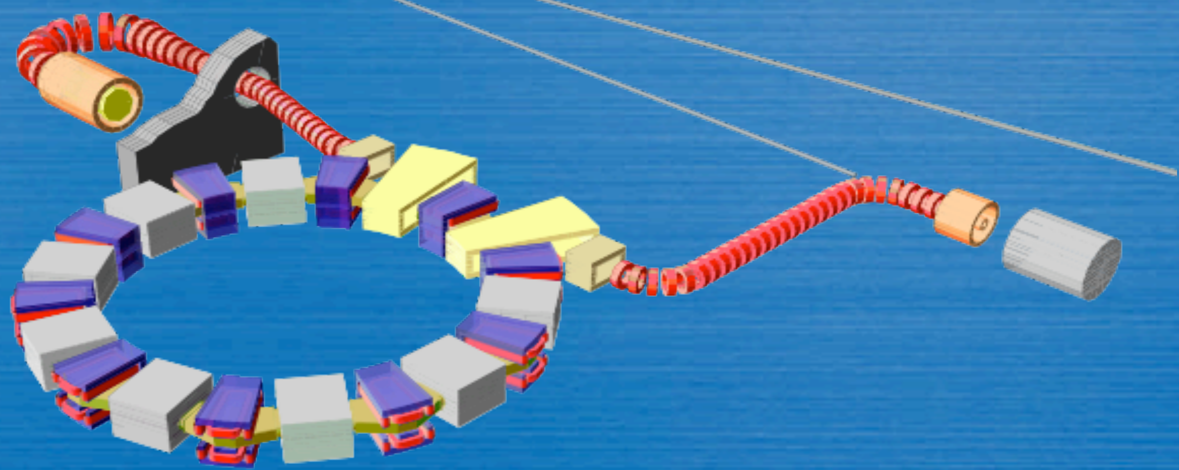
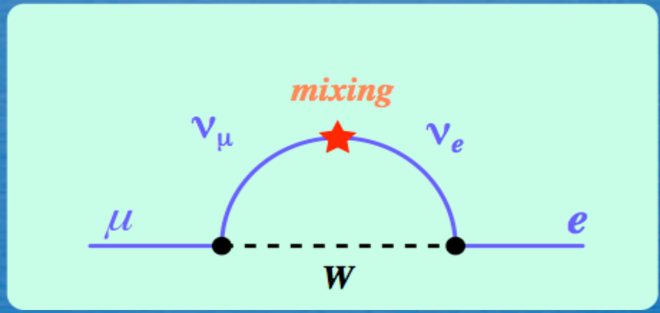


Muon LFV

- Charged leptons do mix via ν oscillation.
- However, it is very weak for charged leptons due to GIM-like mechanism.

$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \sum_i \left| U_{\mu i} U^*_{ei} \frac{m^2_{\nu_i}}{M^2_W} \right|^2 \simeq 10^{-60} \left(\frac{m_\nu}{10^{-2}\,\mathrm{eV}} \right)^4$$

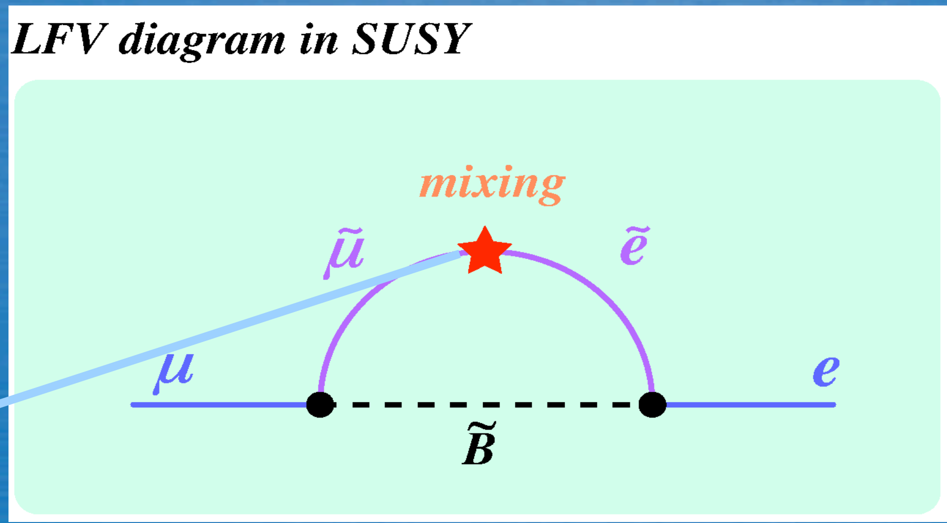


- Thus, observation of μ-e transition immediately indicates physics beyond the Standard Model of particle physics.

SUSY and slepton mixing

- Large top Yukawa couplings result in sizable off-diagonal components in a slepton mass matrix through radiative corrections, and that implies observable levels of LFV in some models of SUSY-GUT
  Barbieri and Hall, 1994

$$
\begin{pmatrix}
m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\
\Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\
\Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}}
\end{pmatrix}
$$



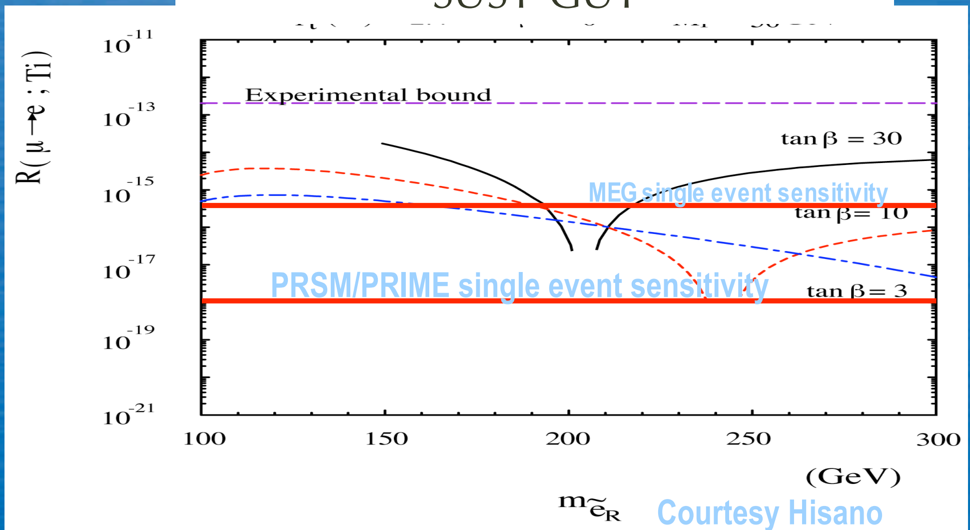
Charged LFV

Physics of slepton Mass Matrix

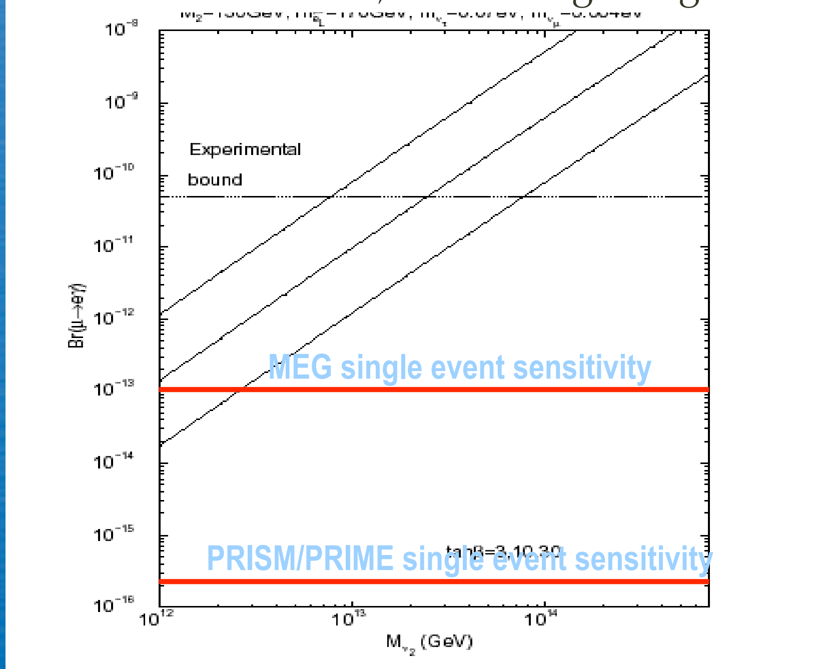
SUSY-GUT & SUSY Seesaw Prediction

Process	Current Limit	SUSY-GUT level
$\mu N \rightarrow e N$	10^{-13}	10^{-16}
$\mu \rightarrow e \gamma$	10^{-11}	10^{-14}
$\tau \rightarrow \mu \gamma$	10^{-6}	10^{-9}

SUSY-GUT



SUSY+Seesaw, MSW Large Angle



μ-e Conversion Process

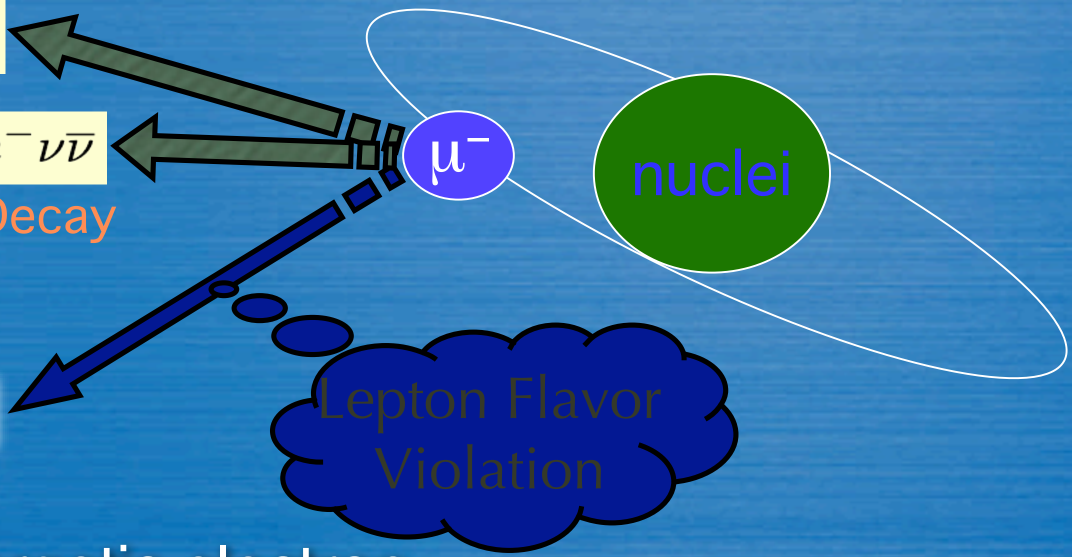
- Muonic Atom (1S state)

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A, Z-1)$$

Muon Decay in Orbit

$$\mu^- \rightarrow e^- \nu \overline{\nu}$$

Michel Decay



- μ-*e* Conversion

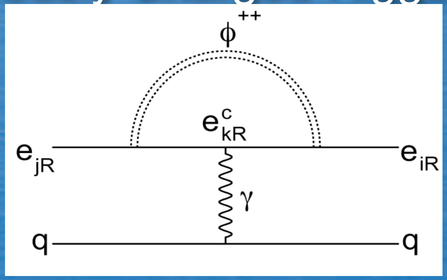
$$\mu^-(A,Z) \rightarrow e^- + (A,Z)$$

Coherent Process

  - Emission of mono-energetic electron $E_{max} = (M_\mu - B_\mu)$ MeV (~105 MeV)
  - $R_{\mu e} \equiv \Gamma(\mu^- N \rightarrow e^- N) / \Gamma(\mu^- N \rightarrow \nu_\mu N(Z-1))$

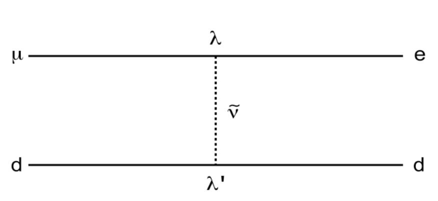
Physics in μ-e Conversion

- SUSY-GUT
- SUSY Seesaw
  - BR ~ 10^{-15}
- Doubly Charged Higgs Boson



  - Logarithmic enhancement in a loop diagram for $\mu^- N \to e^- N$, not for $\mu \to e\gamma$
  - Λ ~ 1 PeV for PRISM/PRIME
    - M. Raidal and A. Santamaria, PLB 421 (1998) 250

- SUSY with R-parity Violation



  - $|\lambda'_{211}\lambda_{212}| < 6 \times 10^{-12}$ for PRISM/PRIME
  - Faessler et al., NPB 587 (2000) 25-44
- Leptquarks
- Heavy Z'
  - MZ' > (5-100) TeV for $R_{\mu e}$~10^{-16}
  - J. Bernabeu et al., NPB 409 (1993)69-86
- Compositeness
- Multi-Higgs Models

$$\Lambda > 3000 \text{ TeV} \sqrt{\eta_q}$$

η_q:model dependent combination of couplings, mixings, etc.

$\mu^- N \rightarrow e^- N$ vs. $\mu \rightarrow e\ \gamma$

- $\mu^- N \rightarrow e^- N$ (PRISM/PRIME,MECO)
- Sensitive to non-photonic process

- $\mu \rightarrow e\ \gamma$ (MEG)
- $B(\mu \rightarrow e\ \gamma) = 200 \times B(\mu^- N \rightarrow e^- N)$ for photonic process

Physics is Complementary

- μ^- beam < μ^+ beam
- No accidental backgrounds
- Requires "state-of-the-art" muon beam

- Surface muon beam exists
- Accidental background dominates
- Requires "state-of-the-art" Detector

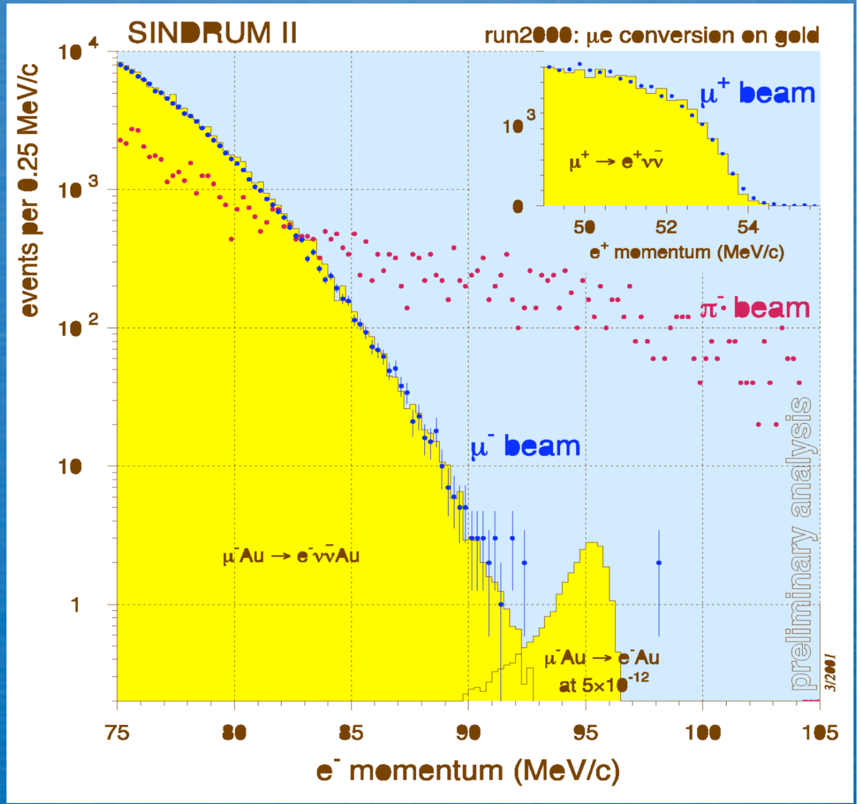
Different Experimental Techniques

Different potential systematics

Both are "must do" to maximize potential discovery

Backgrounds in $\mu^- N \rightarrow e^- N$

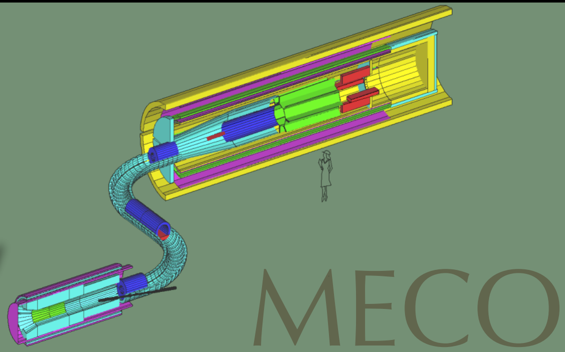
- No accidental backgrounds
- Radiative pion capture
  - Must suppress pions in beam
- Muon Decay in Orbit
  - $E_{max} = E_{LFV}$
    $dN/dE_{MDO} \propto (E_{LFV} - E_{MDO})^5$
  - $N_{bg} = 0.25$ for $R_{\mu e} = 10^{-18}$
  - ΔE_e=500 keV FWHM given by ΔE uncertainty in muon stopping target



PRISM/PRIME for $\mu^- N \rightarrow e^- N$

A good beam is essential for a good $\mu^- N \rightarrow e^- N$ exp.

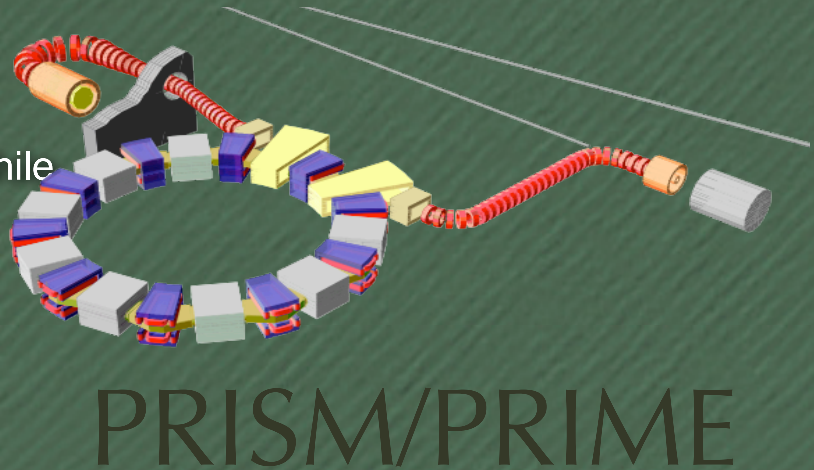
- High muon intensity
  - More than 10^{12} μ^-/sec
- Pulsed beam
  - Rejection of background coming from proton (mostly pions)



- Narrow energy spread

  $\Delta E/E = \pm 0.5\sim 1.0$ MeV
  - Thinner muon-stopping target
  - Thus, better e^- momentum/energy resolution while keeping muon stopping efficiency
- Less beam contamination
  - Practically no pion contamination

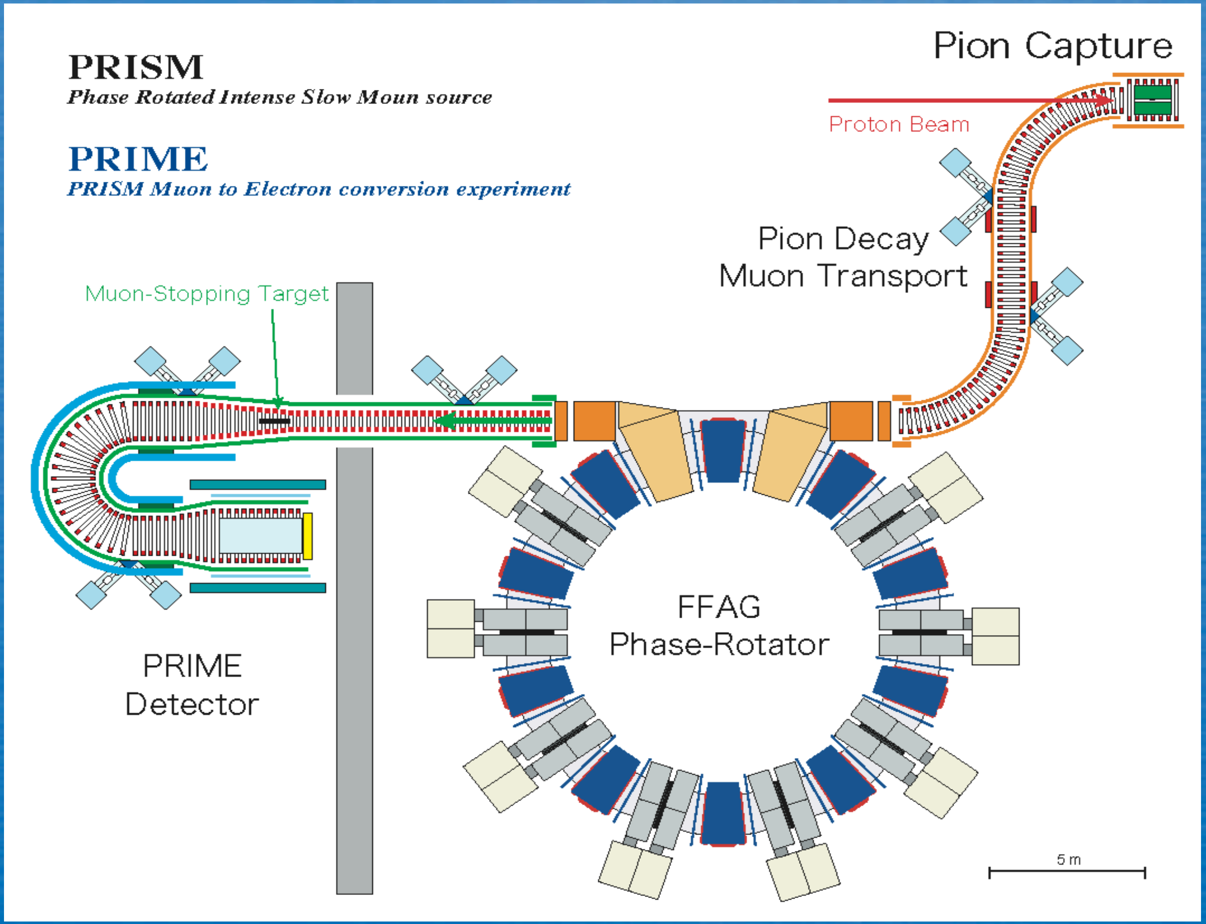
  $\pi/\mu \sim 10^{-18}$



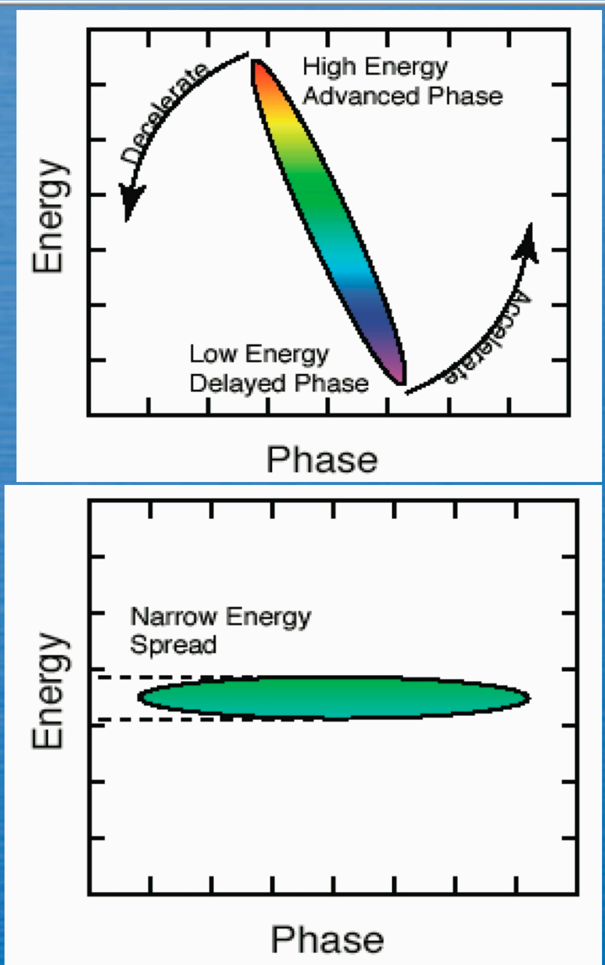
PRISM

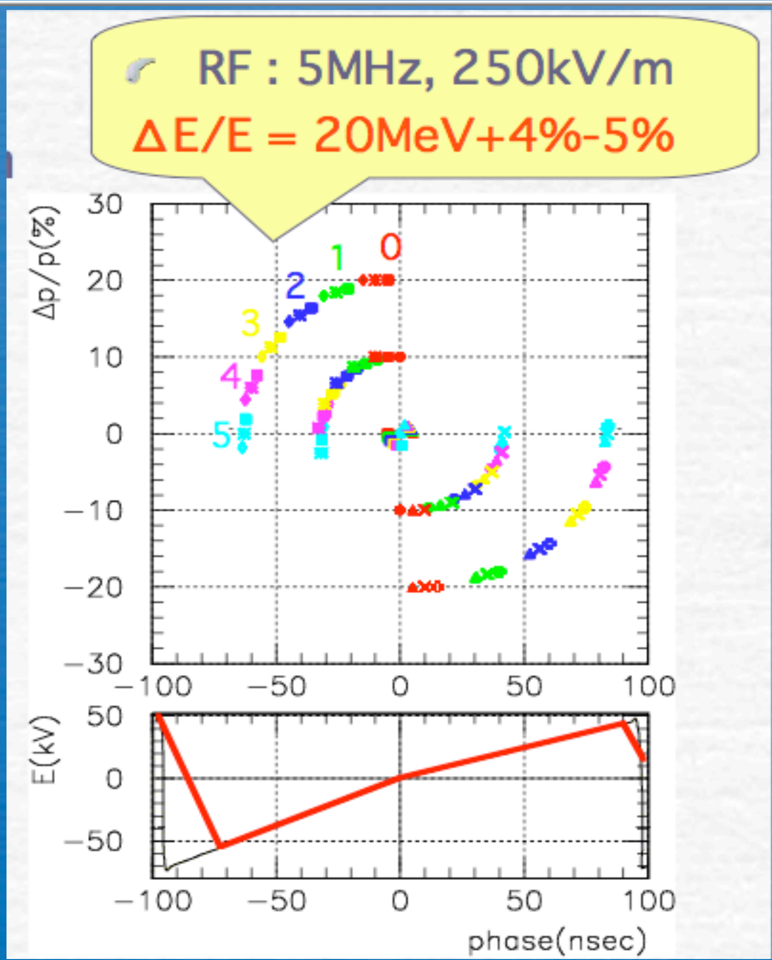
Phase-Rotated Intense Slow Muon source

- High Intensity
  - 10^{11}-10^{12} $\mu^{\pm}$/sec
- High Brightness
  - ±0.5 ~ 1.0 MeV
- High Purity
  - $\pi/\mu \sim 10^{-18}$
- Low Energy
  - 20 MeV (68 MeV/c)
- Pulsed
  - 100 Hz



What is the Phase-Rotation





PRIME

PRIsm Muon-Electron conversion

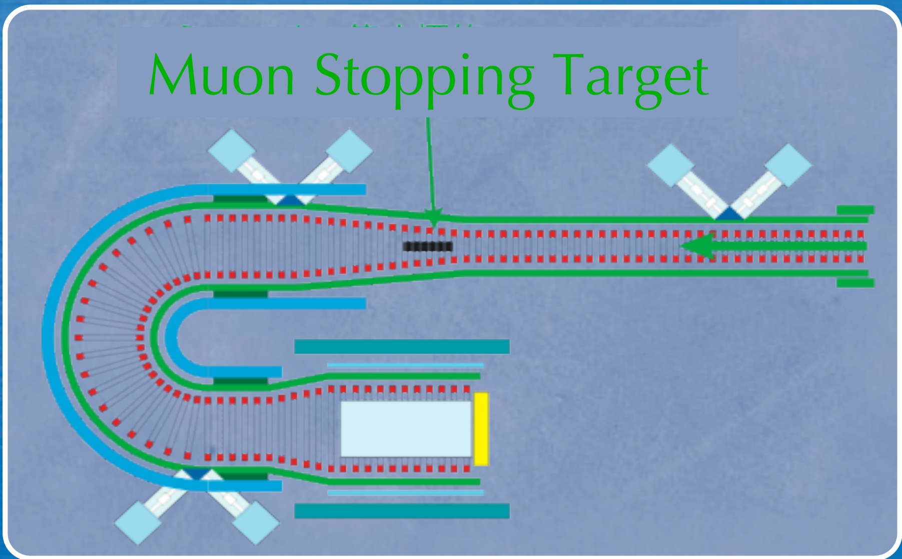
- Utilizes the advantage of PRISM Beam
  - Hight Intensity, High Brightness, High Purity
  - Pulse Frequency: 100 Hz
  - Pulse Duration: 200 ns
    → Instantaneous Rate: 10^{10} muons/sec
- Unwanted particles must be physically suppressed.
  → Curved-Solenoid Muon Transport
  (from MECO)

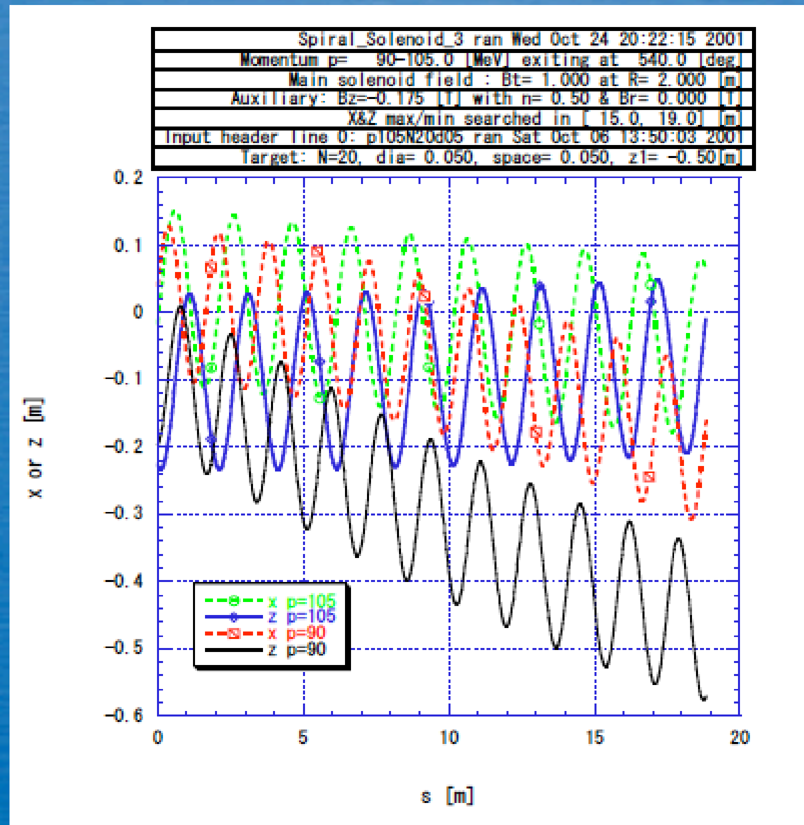
Spiral Solenoid Spectrometer

- Vertical drift of charged particles in torus magnetic field

$$\frac{1}{0.3B}\frac{s}{R}\frac{(p_l^2+\frac{1}{2}p_t^2)}{p_l}$$

D: drift distance
B: magnetic field
s/R: bending angle
pl: longitudial momentum
pt: transverse momentum





Sensitivity

- Proton Driver: 0.75 MW
- Muon yield depends on technology choice in pion capture section, such as target material, magnetic field strength:
  typically $0.3 \sim 2 \times 10^{11}$ μ^{-}/sec
- PRIME acceptance: 40%
- A few nominal years (several 10^{7}sec) of run

- **Single Event Sensitivity ~10^{-18}**

Conclusion

- μ-e Conversion is very important.
- Super muon beam, PRISM, for μ-e Conversion.
- The experiment that utilizes PRISM beam, PRIME, could search for μ-e conversion down to 10^{-18} level.

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